SD Department of Environment & Natural Resources
Watershed Protection Program
Total Maximum Daily Load

Lake Hendricks Watershed, Brookings County South Dakota
January, 1999

These TMDLs were developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by the US Environmental Protection Agency. The 1998 303(d) Waterbody List identified Lake Hendricks as impaired by a measure of Trophic State Index (TSI), which serves as an indicator of the trophic condition of the lake, and accumulated sediment. TMDLs for total phosphorus and accumulated sediment have been developed and are supported below.

TMDL Summary

Waterbody Name	**Lake Hendricks**
Hydrologic Unit Code (HUC)	07020003
TMDL Pollutant	**Total phosphorus**
Water Quality Target	Inlake phosphorus Trophic State Index < 65 (yearly average)
TMDL Goal	50 % reduction in phosphorus
303(d) Status	1998 303(d), Priority 1, Pages 22, 30, 33
Impaired Beneficial Uses	Warmwater semipermanent fish life propagation; immersion recreation; limited contact recreation
Reference Document	Diagnostic/Feasibility Study Report Lake Hendricks/Deer Creek Watershed Brookings South Dakota, 1993

TMDL Summary

Waterbody Name	**Lake Hendricks**
Hydrologic Unit Code (HUC)	07020003
TMDL Pollutant	**Accumulated sediment**
Water Quality Target	Removal of 1 million cubic yards of sediment
TMDL Goal	Six foot increase in lake depth (100 surface acre area)
303(d) Status	1998 303(d), Priority 1, Pages 22, 30, 33
Impaired Beneficial Uses	Warmwater marginal fish life propagation; immersion recreation; limited contact recreation
Reference Document	Diagnostic/Feasibility Study Report Lake Hendricks/Deer Creek Watershed Brookings South Dakota, 1993

I. Executive Summary:

- ***Waterbody Description and Impairments***

Lake Hendricks is a glacial lake located on the South Dakota-Minnesota border approximately 20 miles northeast of Brookings, South Dakota. The surface area of the lake is 1,534 acres. The contributing watershed area is 31,693 acres. Approximately 80% of the watershed area is in South Dakota, and 20% of the watershed area in Minnesota. Upper Deer Creek drains the major subwatershed, and flows into the southwest end of the lake. Minnesota County Ditch 11 drains the other major subwatershed area, and flows into the southeast side of the lake. An unnamed tributary drains a smaller subwatershed to the northwest, and enters at the southwest side of the lake.

The main concerns with Lake Hendricks are degradation of water quality, excessive algae and weed growth associated with the high nutrient concentrations, and decreased lake depth caused by historic sedimentation.

- ***Stakeholder Description***

Landowners and operators
Recreational users
City of Hendricks
Brookings County, South Dakota
Deuel County, South Dakota
Lincoln County, Minnesota
Brookings Conservation District
East Dakota Water Development District

- ***Intent to Submit as a Clean Water Act Section 303(d) TMDL***

In accordance with Section 303(d) of the Clean Water Act, the South Dakota Department of Environment and Natural Resources submits for EPA, Region VIII review and approval, the phosphorus and accumulated sediment total maximum daily loads (TMDLs) for Lake Hendricks as provided in this summary and attached document. These TMDLs have been established at a level necessary to meet the applicable water quality standards for nutrients and sediment with consideration of seasonal variation and a margin of safety. The following designated use classifications will be protected through implementation of this TMDL: warmwater marginal fish life propagation, immersion recreation, and limited contact recreation. Other beneficial uses that may improve by the general improvement in water quality are: wildlife propagation, stock watering and irrigation.

II. Problem Characterization:

Waterbody description

- ***Maps (See Figure 1)***

- ***Waters Covered by TMDL***

Lake Hendricks

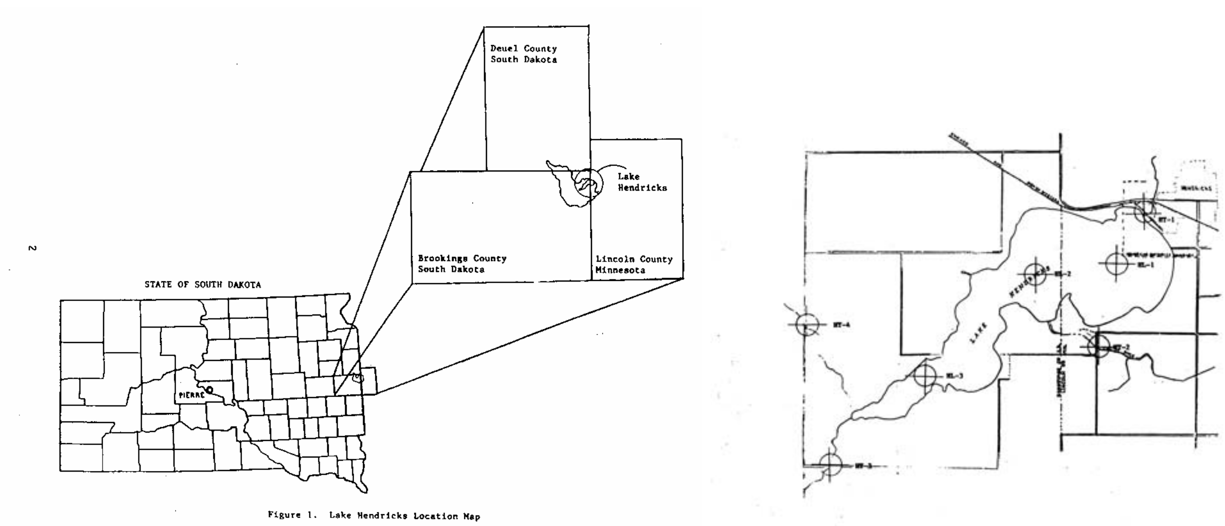

Figure 1 Lake Hendricks location

- ***Rationale for Geographic Coverage***

The population segment most directly affected by the degradation of Lake Hendricks is the city of Hendricks, Minnesota (population 580). Retail establishments within the city of Hendricks such as boat dealers, gas stations, grocery stores, and bait vendors rely heavily on business from residents and recreational users of the lake.

It was found that the total population represented within a 50 mile radius of Lake Hendricks is 332,500 persons. Sixty-four percent of this population resides in South Dakota, with the remaining 36% residing in Minnesota. A very high proportion of this population is young adults as a result of it being within 20 miles of South Dakota State University which is the states largest university. The large number of young adults in the immediate area places a high demand on Lake Hendricks for summer water sports such as swimming and boating. The young adults also place a high demand on the lake for winter recreational activities such as cross-country skiing, snowmobiling, and ice fishing.

Lakeshore development includes 102 lakeside residences, numerous farms, and the city of Hendricks, Minnesota. Other developments include a city park, four public access areas, and a golf course. Lake Hendricks experiences extensive public use because of the recreational facilities that have been developed over the years.

Land use in the Lake Hendricks watershed is 89.6% agricultural, involving either livestock or crop production. The table below provides a summary of land uses and percentages for the entire watershed:

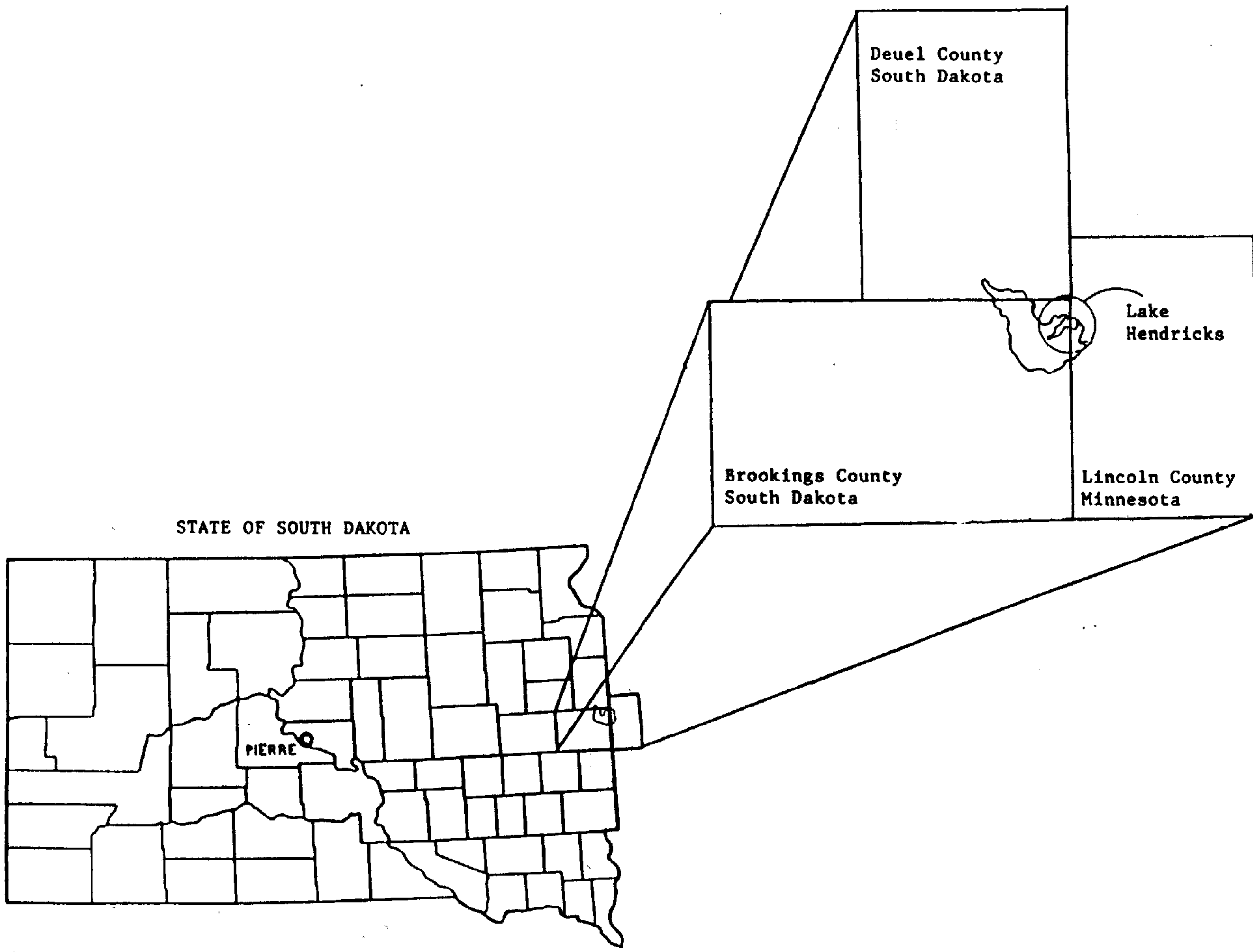

Figure 1. Lake Hendricks Location.

Depending on the fish and macroinvertebrate species dwelling within Deer Creek and Lake Hendricks, continued degradation could result in a shift in species composition due to the pollution tolerance levels of these native species.

The Minnesota Pollution Control Agency started a Citizen Lake-Monitoring Program at Lake Hendricks in 1988. Some of the most useful information obtained from this program are Secchi disk measurements, and corresponding ranking of water conditions. Water conditions are ranked for recreational use and physical/aesthetic quality.

Data collected from the citizen lake monitoring activities indicated that water quality in Lake Hendricks is much better in the spring than in mid- to late-summer. The data also shows that swimming is impaired throughout large portions of the summer due to aesthetic issues associated with heavy algal blooms. The water quality has even degraded to the point where boating and limited contact recreation are affected during the worst algae blooms.

- ***Probable Sources***

According to the watershed analysis, two areas (the Upper Deer Creek subwatershed and the Minnesota County Ditch #11 subwatershed) contribute significant nutrient loads. The sediment load to the lake from the tributaries does not appear to be significant; however, the volume of sediment in the lake basin indicates that sedimentation was a problem, historically. There is limited shoreline erosion that contributes to the sediment problem.

As identified in the lake assessment final report, nutrients are the main cause for the intense blue-green algae blooms on Lake Hendricks. If the ratio of total nitrogen to total phosphorus is greater than 10:1, phosphorus is determined to be the limiting nutrient for algal growth. The ratio in Lake Hendricks during the sampling conducted in 1991-92 was generally greater than 10:1. This indicates that phosphorus was the limiting nutrient for algal growth. Usually a significant relationship exists between the inlake total phosphorus concentrations and chlorophyll *a*. Chlorophyll *a* is an estimate of algal biomass. Higher concentrations of phosphorus result in more chlorophyll *a* and, consequently, blue-green algae. Blue-green algae are more easily controlled through reductions in total phosphorus rather than total nitrogen. This is primarily due to the larger varieties of sources for nitrogen. Blue-green algae also have the ability to manufacture their own usable nitrogen from atmospheric sources in the absence of other sources.

III. TMDL Endpoint:

- ***Description***

The Total Maximum Daily Load (TMDL) target for Lake Hendricks is based on the loads calculated during the lake and watershed assessment conducted in 1991 and 1992, and data collected during the 1994 Statewide Lakes Assessment. The watershed assessment project identified the pollution problems and sources. The problems identified are nutrients entering from the watershed and lack of water depth within the lake due to accumulated sediment. Both of these problems reduced the lake's ability to provide for designated beneficial uses. Sediment loads from the watershed were determined to be insignificant.

The endpoint or TMDL target is based on the trophic status of the lake. The TSI (Carlson, 1977) is based on the nutrient (phosphorus) content. In this case, Lake Hendricks is extremely hypereutrophic based on data collected in 1991-92 and 1994. The mean TSI for phosphorus is 75.31 (Figure 1). A value of 65 is the lower end of the hypereutrophic range which still indicates a lake of extreme nutrient content. To drop the trophic state from 75.31 to 65 would require a 50% reduction of total phosphorus loadings from the watershed (Figure 1). A corresponding TSI value of 65 would be the measure of reaching the TMDL. After this target has been reached a reassessment should be completed to reevaluate the state of water quality within the Lake Hendricks watershed.

Reduction/Response Model (Lake Hendricks)

Inlake total phosphorus concentrations are a function of the total phosphorus load delivered to the lake by the watershed. Vollenweider and Kerekes (1980) developed a mathematical relationship for inflow of total phosphorus and the inlake total phosphorus concentration. They assumed that if you change the inflow of total phosphorus you change inlake phosphorus concentration a relative but steady amount over time. The variables used in the relationship are:

1) $[\overline{P}]_{\lambda}$ = Average inlake total phosphorus concentration

2) $[\overline{P}]_{i}$ = Average concentration of total phosphorus which flow into the lake

3) $\overline{T}_{p}$ = Average residence time of inlake total phosphorus

4) $\overline{T}_{w}$ = Average residence time of lake water

Data collected during the project (1991 and 1992) provided enough information to estimate $[\overline{P}]_{\lambda}$, $[\overline{P}]_{i}$, and $\overline{T}_{w}$. In order to estimate the residence time of total phosphorus ($\overline{T}_{p}$) it was necessary to back calculate Equation 1 below, and solve for $\overline{T}_{p}$ by forming Equation 2 (Wittmuss, 1996).

{Equation 1} $$[\overline{P}]_{\lambda} = \left[\frac{\overline{T}_{p}}{\overline{T}_{w}}\right][\overline{P}]_{i}$$

{Equation 2} $$\left(\overline{T}_{p}\right) = \frac{[\overline{P}]_{\lambda}}{[\overline{P}]_{i}}\left(\overline{T}_{w}\right)$$

Values for $\left[\overline{P}\right]\lambda$, $\left[\overline{P}\right]i$, $\overline{T}_w$ were determined in the following manner:

$\left[\overline{P}\right]\lambda$ was determined by averaging all of the surface total phosphorus samples from 1991-92 and the 1994 Statewide Lakes Assessment samples from Lake Hendricks.

$\left[\overline{P}\right]i$ was determined by adding all of the input loadings for total phosphorus in milligrams and dividing that number by the total number of liters that entered the lake. The values for both of these numbers came from tributaries, groundwater, and the atmosphere.

$\overline{T}_w$ was determined by averaging the total volume of Lake Hendricks (8,000 acre-feet) by the total inputs of water into the lake (5,102 acre-feet/days of discharge measurements).

$$\overline{T}_w = {}^{8{,}000 acre-feet}\!\Big/_{5{,}102 acre-feet/210 days} = 329.3 \text{ days} = 0.902 \text{ year}$$

The final values for $\left[\overline{P}\right]\lambda$ and $\left[\overline{P}\right]i$ are:

$\left[\overline{P}\right]\lambda$ = 0.139 mg/L $\qquad$ $\left[\overline{P}\right]i$ = 0.407 mg/L

By placing the numbers in the proper places as discussed in Equation 3, $\overline{T}_p$ would be:

$$\left(\overline{T}_p\right) = \left[\frac{0.139}{0.407}\right](0.902) = 0.308 \text{ years} = 112.4 \text{ days}$$

Referring back to Equation 1, reducing the inputs of total phosphorus, the equation would estimate the reduction of inlake total phosphorus. This is assuming constant inputs of water. Theoretically the retention time for total phosphorus should also be reduced. With only one year of sampling, there is no way to estimate the reduction in the retention time of total phosphorus. The $\overline{T}_p$ constant (0.308) derived from the data will be used in Equation 1. After estimating the amount of reduction of inlake phosphorus after a reduction of input phosphorus, Carlson's (1977) equation can be used to see the reduction of chlorophyll *a* (Chl *a* = $0.068TP^{1.46}$). As can be seen in Table 1, a 50% reduction in phosphorus inputs to Lake Hendricks will reduce the inlake chlorophyll *a* concentration by an estimated 64%. The 50% reduction would also lower the chlorophyll TSI value to the eutrophic line (Figure 2). As stated above, this is considering no reduction in the retention time of total phosphorus. If the retention time is lowered, the lake should experience even lower inlake concentrations and lower chlorophyll *a* concentrations. As the input concentrations of phosphorus are lowered, the lake will see algal blooms that are less intense and of a shorter duration. These tables and graphs are predictive on the data collected during the study. Actual changes can be expected to be different depending on runoff values and the extent of change that occurs in the volume of water passing through Lake Hendricks.

Table 1. Effects of Reducing Phosphorus to Lake Hendricks

Reduction of Phosphorus Inputs	Input Phos. Concentration	InLake Phos. Concentration[1]	Chlorophyll *a* [1]	Percent Reduction Chlorophyll *a*	Phosphorus TSI	Chlorophyll TSI
0%	0.407	0.139	91.20	0%	75.31	74.84
10%	0.366	0.125	78.20	14%	73.79	73.34
20%	0.325	0.111	65.85	28%	72.09	71.65
30%	0.285	0.097	54.18	41%	70.16	69.74
40%	0.244	0.083	43.26	53%	67.94	67.53
50%	0.203	0.069	33.15	64%	65.31	64.92
60%	0.163	0.055	23.93	74%	62.09	61.72
70%	0.122	0.042	15.73	83%	57.94	57.60
80%	0.081	0.028	8.70	90%	52.09	51.79
90%	0.041	0.014	3.16	97%	42.09	41.86

[1] Inlake chlorophyll a concentrations were calculated from inlake total phosphorus concentrations using the equation ($0.068TP^{1.46}$) developed by Carlson (1977).

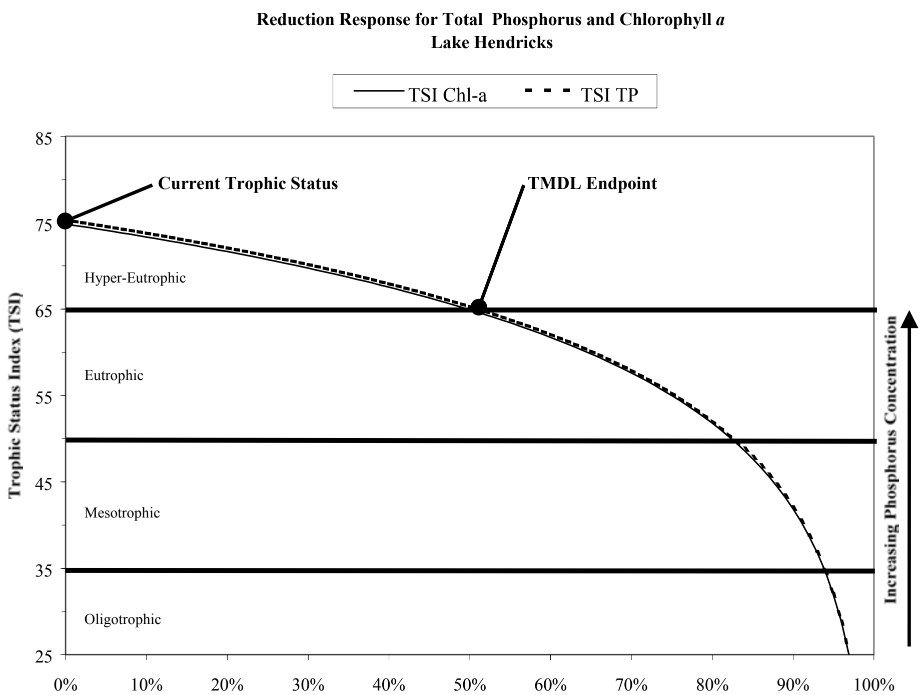

Figure 2. Percent Reduction in Total Phosphorus Loadings to Lake Hendricks

Accumulated Sediment

A survey of the bottom sediments of Lake Hendricks was conducted by a consulting engineering firm during the fall of 1990. The survey produced the following results:

Water Surface Area	1,534.2 acres
Average Water Column Depth	10.0 feet
Average Sediment Column Depth	9.0 feet
Estimated Sediment Volume	22,594,000 cubic yards Or 14,000 acre-feet

The survey indicated that the sediment is distributed evenly throughout the lake at an average depth of nine feet. An elutriate analysis of the sediment indicated that there were not excessive concentrations of toxic substances in the sediment.

Due to the inordinate volume of sediment in Lake Hendricks, whole lake dredging is not feasible. The capability of the equipment, volume of sediment, and cost of removing the sediment combine to make whole lake dredging infeasible.

The removal of sediment by selective dredging would improve the fisheries habitat of the lake, and enhance recreational opportunities. It is recommended that one million cubic yards of sediment be removed. By dredging an average sediment column depth of six feet, about 100 surface acres of the lake would be provided with a water column depth of approximately fifteen to sixteen feet. It is recommended that dredging not be implemented right away.

- ***Endpoint Link to Surface Water Quality Standards***

The first water quality goal for Lake Hendricks is a 50% reduction in phosphorus. The water quality standards target is a Trophic State Index (TSI) of < 65.

The second water quality goal for Lake Hendricks is a six foot increase in lake depth (100 surface acre area). The water quality target is the removal of 1 million cubic yards of sediment.

These two goals will greatly diminish productivity in the lake which in turn will lead to greater support of assigned beneficial uses. This improvement in water quality will insure the following:

a. visible pollutants are controlled;
b. more pollutants will not form in the lake;
c. growth of nuisance aquatic life will be reduced; and
d. improve recreation on the lake through:
    1. increasing aesthetics for swimming and fishing; and
    2. increasing the depth of the lake for boating and fish habitat.

IV. TMDL Analysis and Development:

- ***Data Sources***

The data sources for the development of the Lake Hendricks TMDL were identified as the Phase I Diagnostic/Feasibility Study of Lake Hendricks completed in 1992. This project was funded through Section 314 of the Clean Water Act administered through USEPA Region VIII.

A second data source used for this TMDL development was the 1994 Statewide Lakes Assessment where Lake Hendricks was one of the lakes where data was collected during the summer of 1994. This project was also funded through Section 314 of the Clean Water Act.

- ***Analysis Techniques or Models***

Tributary samples were collected at four sites in the Lake Hendricks watershed. These were chosen for collecting hydrologic and nutrient information from the Lake Hendricks. These monitoring locations were placed at specific areas within the watershed that would best show DENR which sub-watersheds were contributing the largest nutrient and sediment loads. Gauging stations were installed where water quality samples would be collected to record the daily stage of the tributary. The recorders were checked weekly and flow measurements were collected at various stage heights at these sampling locations during the course of the sampling year. The stage and flow measurements were used to develop a stage/discharge table for each site. The stage/discharge table was used to calculate an average daily loading for each site. The loading for each day was totaled for annual loading rate. A full year of data including loadings, water quality concentrations (mg/L) and export coefficients (kg/year) were calculated.

All sites (tributary and outlet) were sampled twice during the first week of snowmelt runoff and once a week thereafter until the runoff stopped in April. Base flow monitoring also took place after the snowmelt runoff ceased. All nutrient and solids parameters were sampled using approved methods documented in the South Dakota's Watershed Protections Programs approved *Standard Operating Procedures for Field Samplers*. The South Dakota State Health Laboratory in Pierre, SD analyzed all samples. The purpose of these samples was to develop nutrient and sediment loadings to determine critical areas in the watershed.

In addition to water quality monitoring, information was collected to complete a comprehensive review of the land use within the Lake Hendricks watershed. Sediment and nutrient loading estimates to Lake Hendricks were calculated using the Universal Soil Loss Equation. Loadings were also estimated for sub-basins within the watershed. The sub-basins analyzed were as follows:

1) Sub-basin 1-H: Area drained by unnamed northwest tributary
2) Sub-basin 2-H: Area drained by Deer Creek
3) Sub-basin 3-H: Area drained by Minnesota County Ditch 11

From the loading estimates, it can be seen that the sub-basins drained by Deer Creek and Minnesota County Ditch #11 carry the greatest load of sediment and nutrients. Since the construction of the soil retention dam on Deer Creek a significant reduction in loads has occurred. The trapping efficiency of this structure is believed to be greater than 85%. It is recommended that best management practices such as conservation tillage, grassed waterways, and filter strips be implemented where needed in the watershed.

The mean total phosphorus concentrations for all inlet sites were relatively similar. The maximum concentration was found at Site HT-2. In general the largest concentrations were found in the spring runoff events in both 1991 and 1992. As with nitrogen, the sources of phosphorus during spring runoff are from animal and domestic waste and nutrient rich agricultural.

Because of the large water volume through Deer Creek, Site HT-3 has the largest phosphorus load to Lake Hendricks. The load of total phosphorus through Site HT-3 is estimated at 3,127 kg (0.71 tons). Since phosphorus sorbs to sediment the increased sediment loads are probably responsible for increasing the particulate portion of the total phosphorus. The total dissolved phosphorus loads to Lake Hendricks are also greatest at Site HT-3. While the loads were higher at the monitoring site on Deer Creek, concentrations of dissolved phosphorus were higher at Site HT-2 on Minnesota County Ditch #11. Sources of phosphorus from the Lake Hendricks watershed include animal waste, runoff from agricultural land, decaying organic matter, and failing septic systems.

- ***Seasonality***

Different seasons of the year can yield differences in water quality due to changes in precipitation and agricultural practices. Seasonality was determined through the analysis of annual loading data. The annual loading data was separated into seasons and compared. This comparison determined that higher loading occurs during the period of spring runoff.

- ***Margin of Safety***

The margin of safety is addressed through dredging. The TMDL target is a 50% reduction in total phosphorus loads to decrease the TSI to <65. After implementing best management practices within the Deer Creek and Minnesota County Ditch #11 subwatersheds to reach the target, additional reductions of phosphorus can be achieved through dredging. Because of the lack of depth in Lake Hendricks, phosphorus is continually recycled from the sediment which is re-suspended throughout the course of the year. This phosphorus becomes available for further nuisance algal growth. With the removal of the 1 million cubic yards of sediment additional reductions will be observed.

The survey of septic systems around Lake Hendricks found that about 11% of the systems may be out of compliance with current constructions standards. As an additional margin of safety measure, it is recommended that an effort be made to address the problem of potentially failing wastewater systems. The majority of the cabin development on the lakeshore is located in Lincoln County, Minnesota.

V. Allocation of TMDL Loads or Responsibilities:

- ***Wasteload Allocation***

There are no point sources of pollutants that are of concern in this watershed, therefore the "wasteload allocation" component of the TMDL is considered a zero value. The TMDL is considered wholly included in the "load allocation" component of the TMDL.

- ***Load Allocation***

The load allocation is the 50% reduction in phosphorus loads. In order to achieve this reduction and arrive at an inlake phosphorus concentration of 0.203 mg/L a variety of best management practices (BMPs) need to be implemented in the watershed. Because of the large water volume through Deer Creek, Site HT-3 has the largest phosphorus load to Lake Hendricks. The load of total phosphorus through Site HT-3 is estimated at 3,127 kg (0.71 tons). This constituted 94% of the total phosphorus load to Lake Hendricks. However, the subwatershed drained by Minnesota County Ditch #11 contributes a higher phosphorus loading on a per acre basis. A 50% reduction in phosphorus loads from each of the 3 main tributaries will result in the target TMDL of a TSI < 65.

Sub-Basin	**Phosphorus**	
	Total Kg	**% Contribution**
SITE HT2 (MINNESOTA COUNTY DITCH)	186	6%
SITE HT3 (DEER CREEK)	3,127	94%
SITE HT4 (UNNAMED NORTHWEST TRIBUTARY)	30	1%
TOTAL PHOSPHORUS LOADS	3,343	100%

- ***Allocation of Responsibility***

It is recommended that Integrated Crop Management practices should be promoted through a program of information and education. Integrated Crop Management practices would include components such as soil testing to determine proper fertilization rates, and scouting of cropland to determine optimum application of pesticides. Cost-sharing should be considered for Integrated Crop Management practices such as soil testing.

There are six to eight livestock operations in the subwatershed drained by Minnesota County Ditch 11 that may be contributing runoff to Lake Hendricks. It is recommended that these livestock operations be rated by means of a feedlot runoff model to determine which facilities are contributing the highest loads of sediment and nutrients. Fecal coliform counts from Site HT-2 (Minnesota County Ditch 11) indicate the presence of animal waste contamination in the watershed. Low cost alternatives to control feedlot runoff, such as diversion of clean water around lot areas or establishment of vegetative buffer strips, should be implemented to the greatest extent possible.

VI. Schedule of Implementation:

A 319 Implementation Project is currently underway within the Lake Hendricks watershed. The Brookings Conservation District is the local sponsor for the project.

VII. Post-Implementation Monitoring:

- ***Description***

Once the implementation project is completed, post-implementation monitoring will be required to assure that the TMDL has been reached and improvements to the beneficial uses occur.

VIII. Public Participation:

The Diagnostic Feasibility Study (watershed assessment) was funded through a $100,000 EPA Section 314 grant. The local community provided a match amount of $42,857 through the East Dakota Water Development District.

- ***Summary of Public Review***

The following table summarizes efforts taken to gain public education, review and comment during development of the TMDL:

Public Meetings/ Personal Contact	***Articles/ Fact Sheets***	***Document Distribution***
Pre-project meetings Funding meeting Mid-project meeting Near-end project meeting Final summary meeting		Interested property land owners City of Hendricks Brookings County, SD Deuel County, SD Lincoln County, MN Brookings Conservation District East Dakota Water Development District
Electronic media	***Mailings***	***Public Comments Received***
December 1998 Assessment Summary added to department website **February, 1999** TMDL Summary advertised on department	**Interested parties** February 17, 1999 **Stakeholders** February 17, 1999 **Daily Newspapers** February 12, 1999	Comments received during project meetings and review of the draft report and findings were considered

website		

IX. Supporting Development Document(s) (attached):

Madison, Ken and Wax, Pete. February 1993. DIAGNOSTIC/FEASIBILITY STUDY REPORT LAKE HENDRICKS/DEER CREEK WATERSHED BROOKINGS SOUTH DAKOTA. South Dakota Clean Lakes, Division of Water Resources Management, South Dakota Department of Environment and Natural Resources, Pierre, South Dakota.